

# A Study of Airline Passenger Susceptibility to Atmospheric Turbulence Hazards

by

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# Background

- Turbulence affects airline passengers in two main areas: ride comfort and injuries
- This study concentrates on the latter-- turbulence encounters that cause accidents (serious injuries)
- The typical turbulence accident scenario is a discrete gust that tosses flight attendants or unbuckled passengers into the ceiling and back to the floor

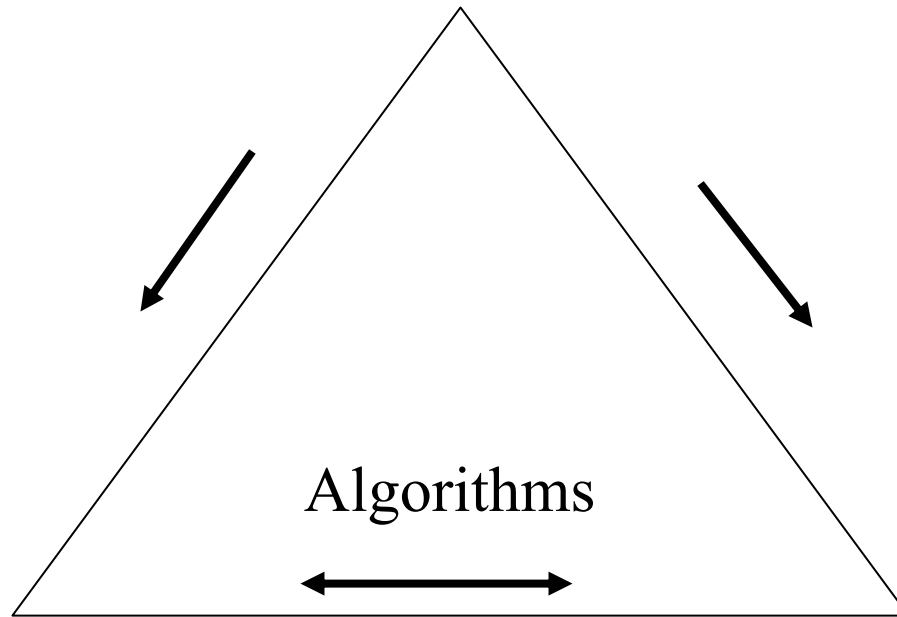
# Background (continued)

- One solution is to develop (airborne) sensors to detect areas of gusts in front of the airplane
- A better understanding of the gust characteristics and threshold levels that cause the accidents is needed
- This understanding will give the sensor developers a target to shoot for

# Gust-Sensor-Airplane Hazard Metrics

Gust

(Amplitude, Gradients/Wavelengths, RMS/TKE/epsilon)



Sensor

(Radar/Lidair/IR moments, Temp/Press/Humidity)

Airplane

(Local states, Collisions, Rigid Body, Loads)

ECS

# Approach

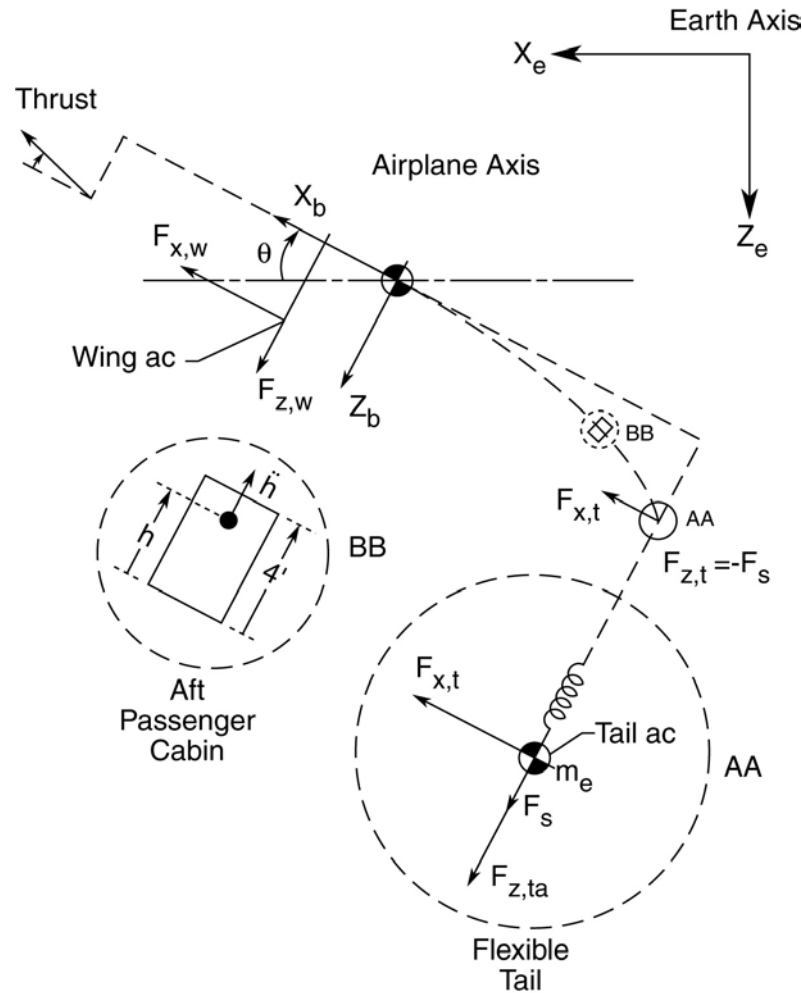
- Develop a math model to predict gust responses
- Extract actual gust velocities from FDR recordings in NTSB accident reports
- Compare math model predictions to actual NTSB data for real accidents

# Desired Math Model

## Characteristics

- Captures first-order effects to vertical gust
- Easy to apply to different size airplanes
- Does not require data from manufacturers
- Does not expose manufacturers to liability for accidents

# Airplane math model

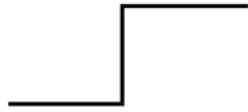


5 DOF (Heave, pitch, velocity, fuselage bending, passenger)

# Airplane Characteristics

- Weight=140,000
- Wing area= 2000 sq. ft.
- Horizontal tail area=550 sq. ft.
- Non-linear lift and drag for wing
- Simple altitude hold autopilot
- Estimated fuselage elastic properties
- Estimated unsteady lift effects on wing

# Gust Shapes Studied



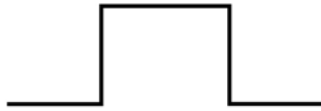
step



ramp



peak



block



cos-ramp



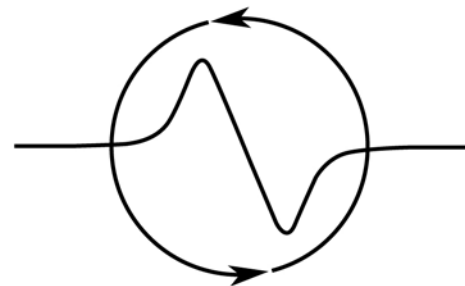
cos-ramp-cos



sine

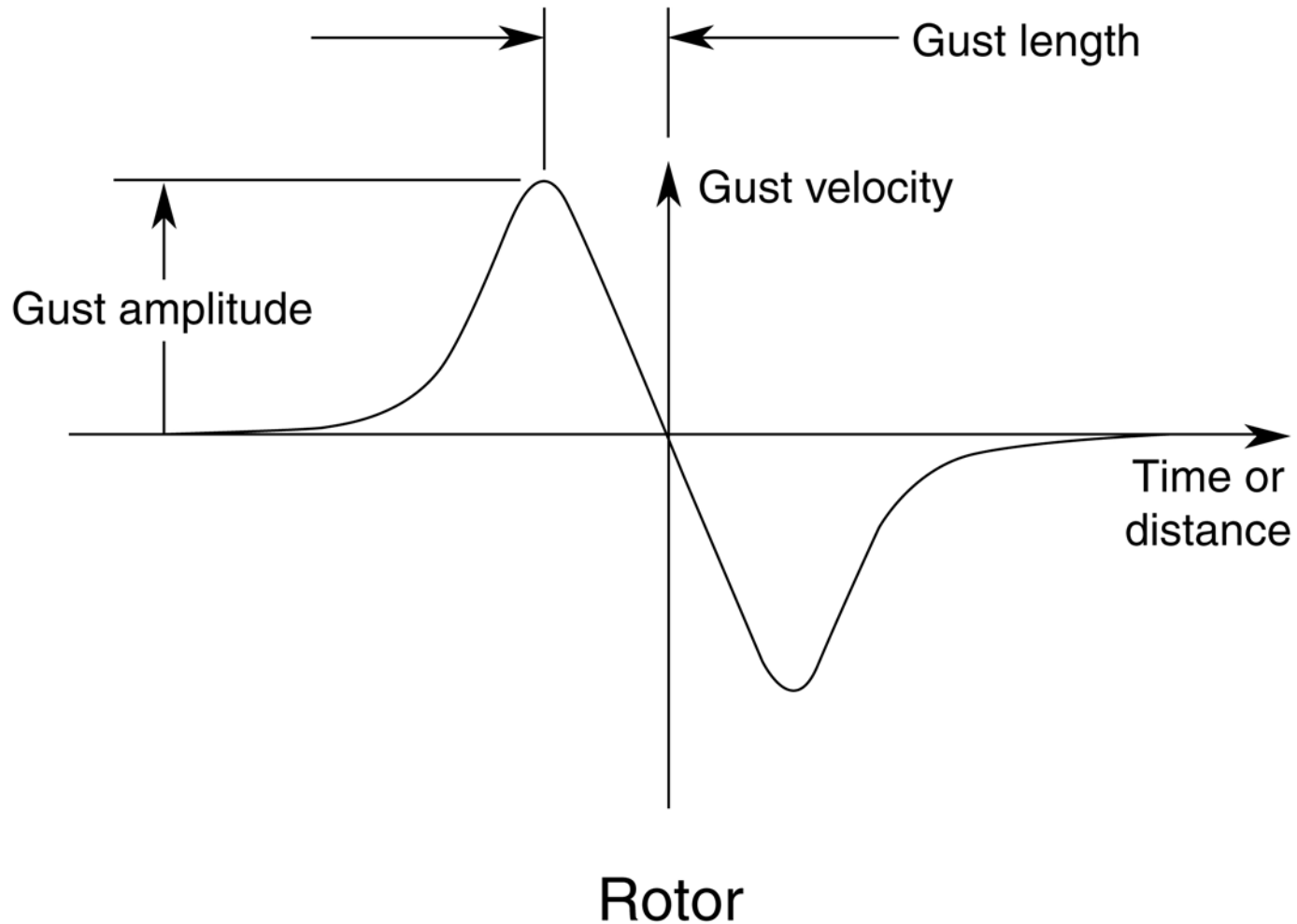


1-cosine



rotor

# Gust Parameters



# Gust amplitudes

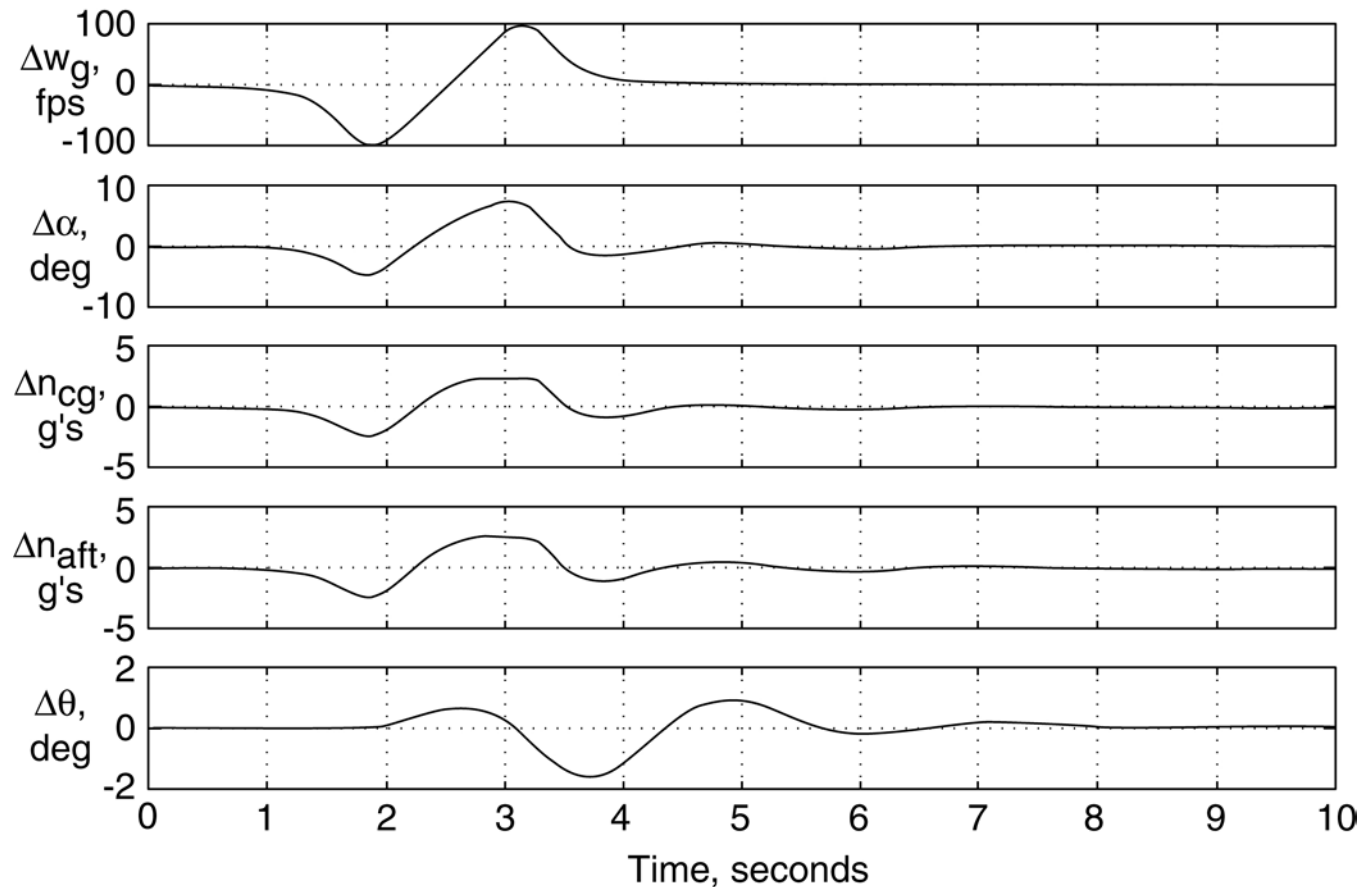
- Airplanes have been certified for 90 fps (TAS) 1-cosine gusts
- Wingrove and Bach show data for 50 fps (TAS) gusts
- Fuller shows 200 fps gusts in thunderstorms and 485 fps gusts near the jet stream

# Gust Scale Lengths for Airplane Response

- “...eddies of 30-2000 ft in extent...” --J.R. Fuller, J of A/C 1995
- Unsteady lift time constant of approximately 2 chords [ $\sim 20$  ft]--Philip Donley, NACA report 997
- 50% lift decrement for .8 span [ $\sim 70$  ft] gusts due to spanwise variations, W.H. Phillips, NACA TN 2416

# Selected time history

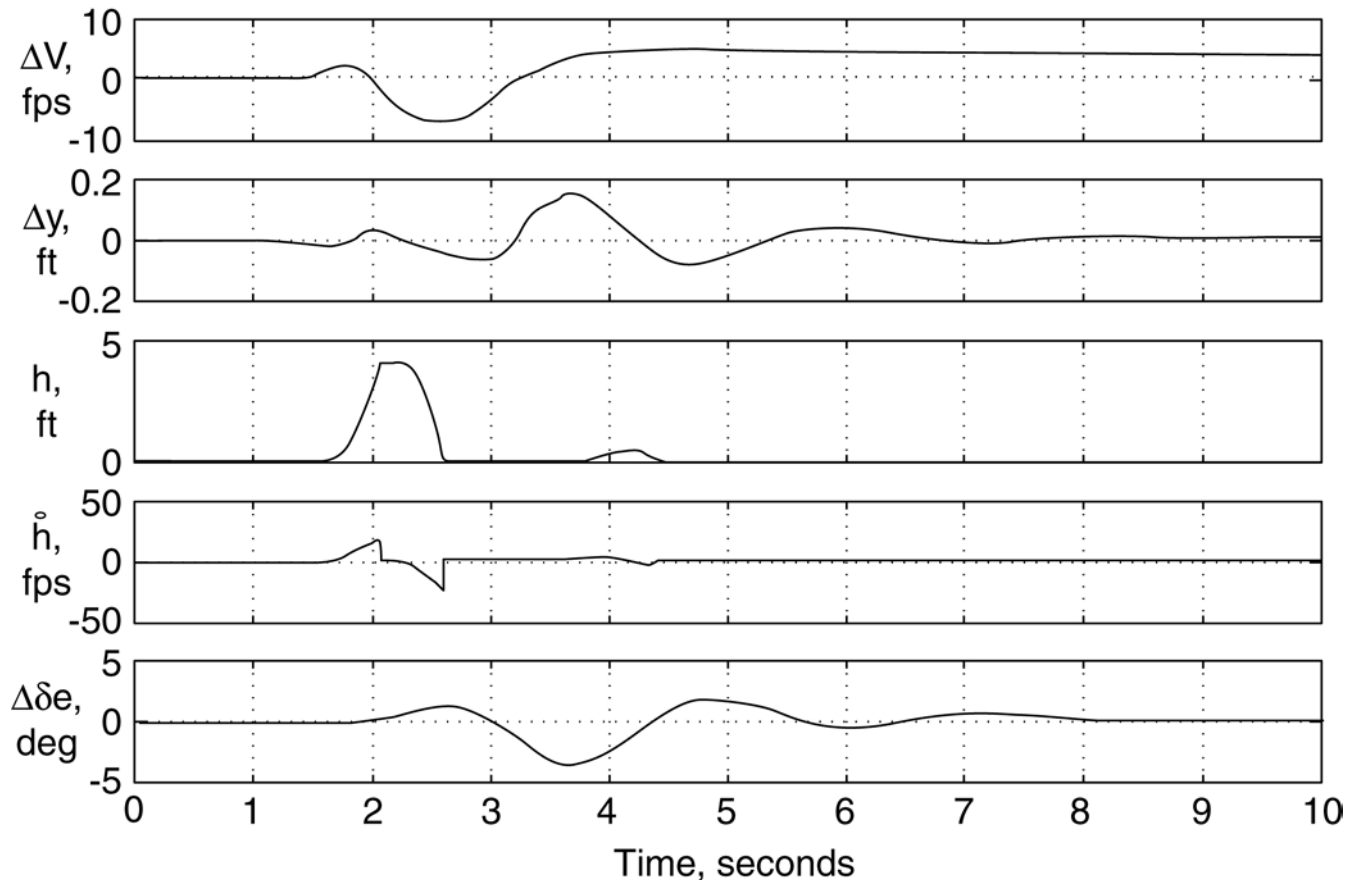
Cruise flight condition, Wing loading=70lb/sq ft



Rotor gust, gust amplitude=-100 fps(true), gust length=500 ft

# Selected time history

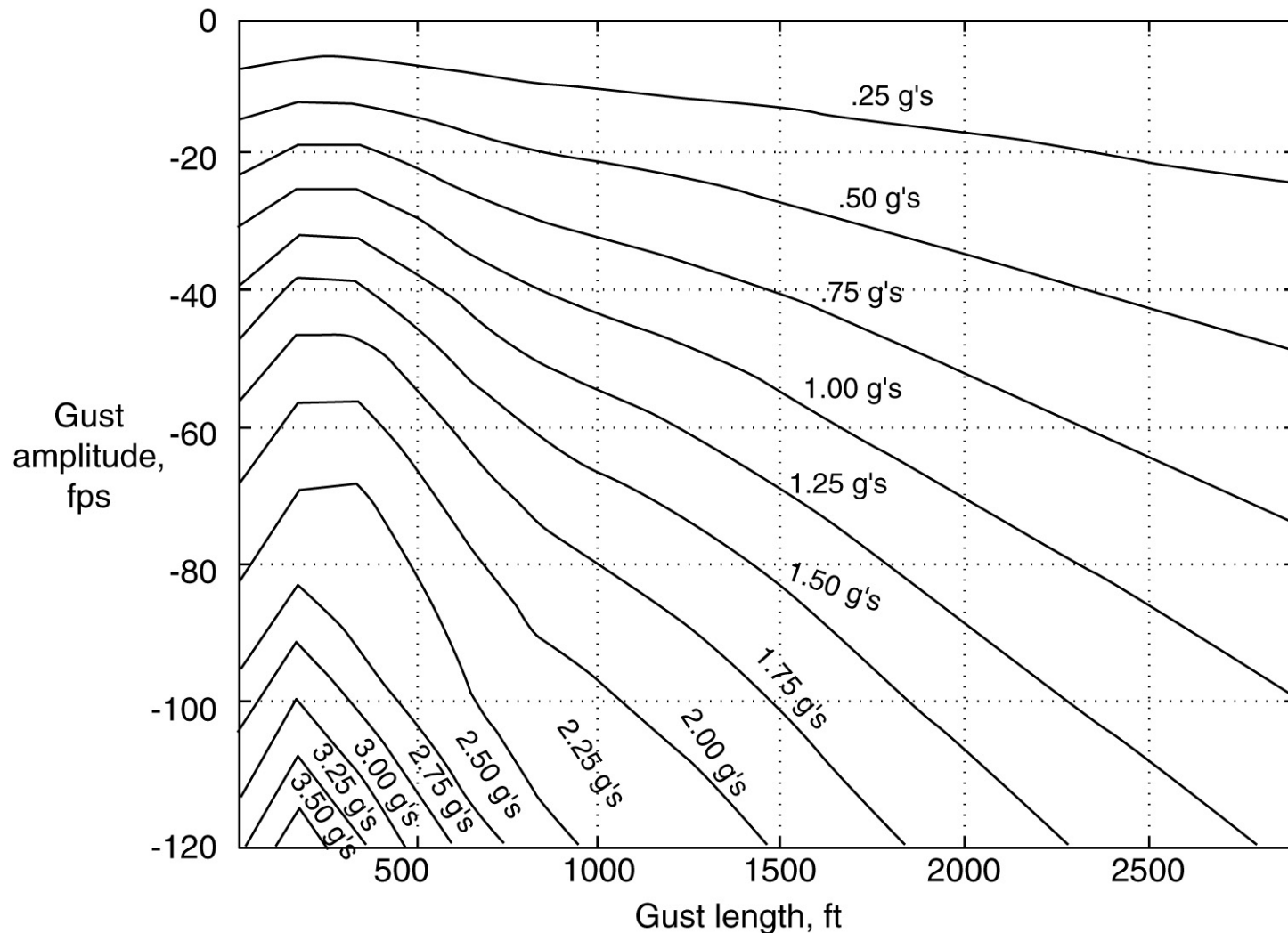
Cruise flight condition, Wing loading=70lb/sq ft



Rotor gust, gust amplitude=-100 fps(true), gust length=500 ft

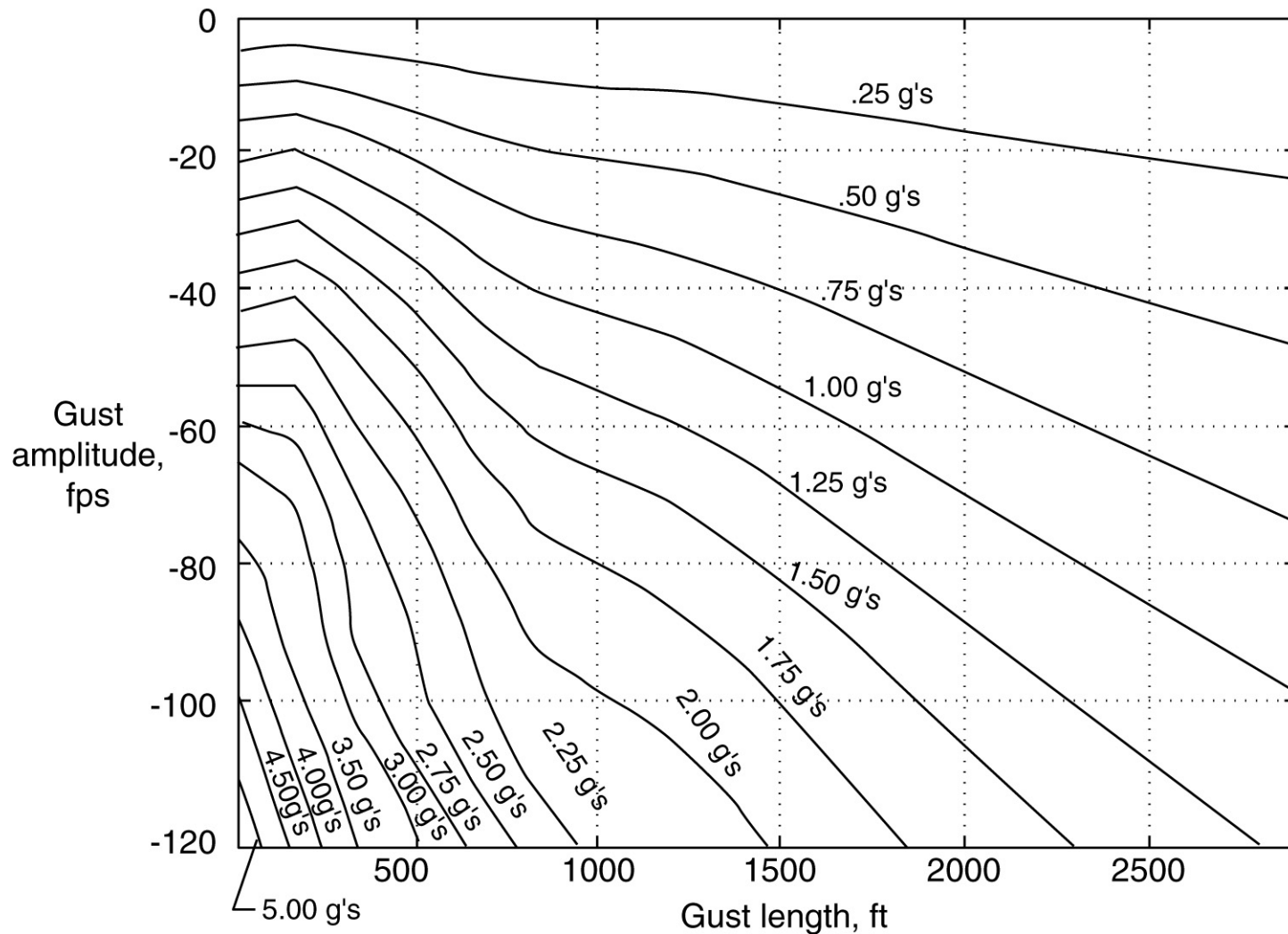
# Max c.g. acceleration contours

Cruise flight condition, wing loading=70 lb/sq ft, rotor gust



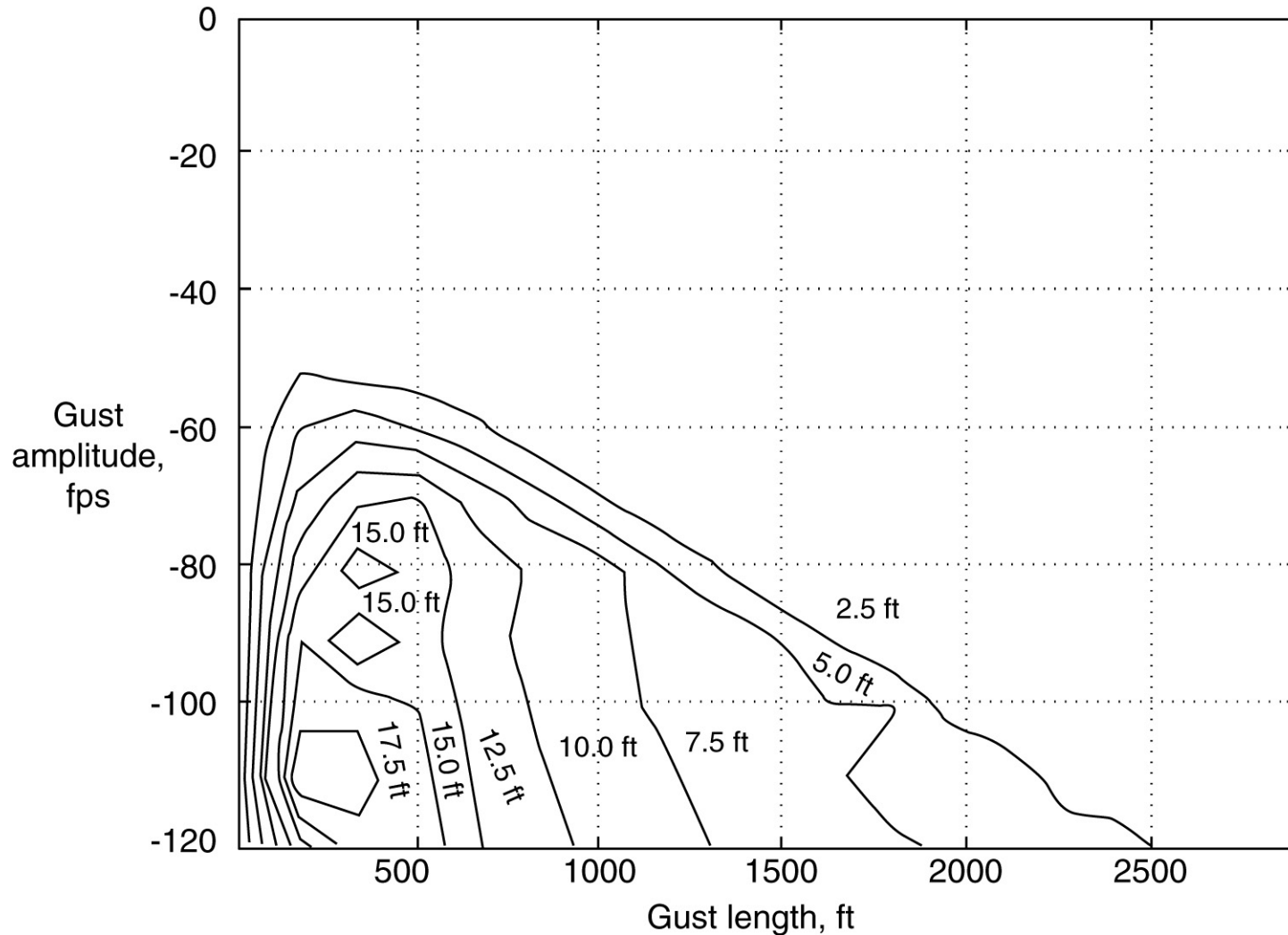
# Max aft acceleration contours

Cruise flight condition, wing loading=70 lb/sq ft



# Equivalent fall height contours

Cruise flight condition, wing loading=70 lb/sq ft



# NTSB Data Analysis

- Equations (Ref. NASA TR R-199)

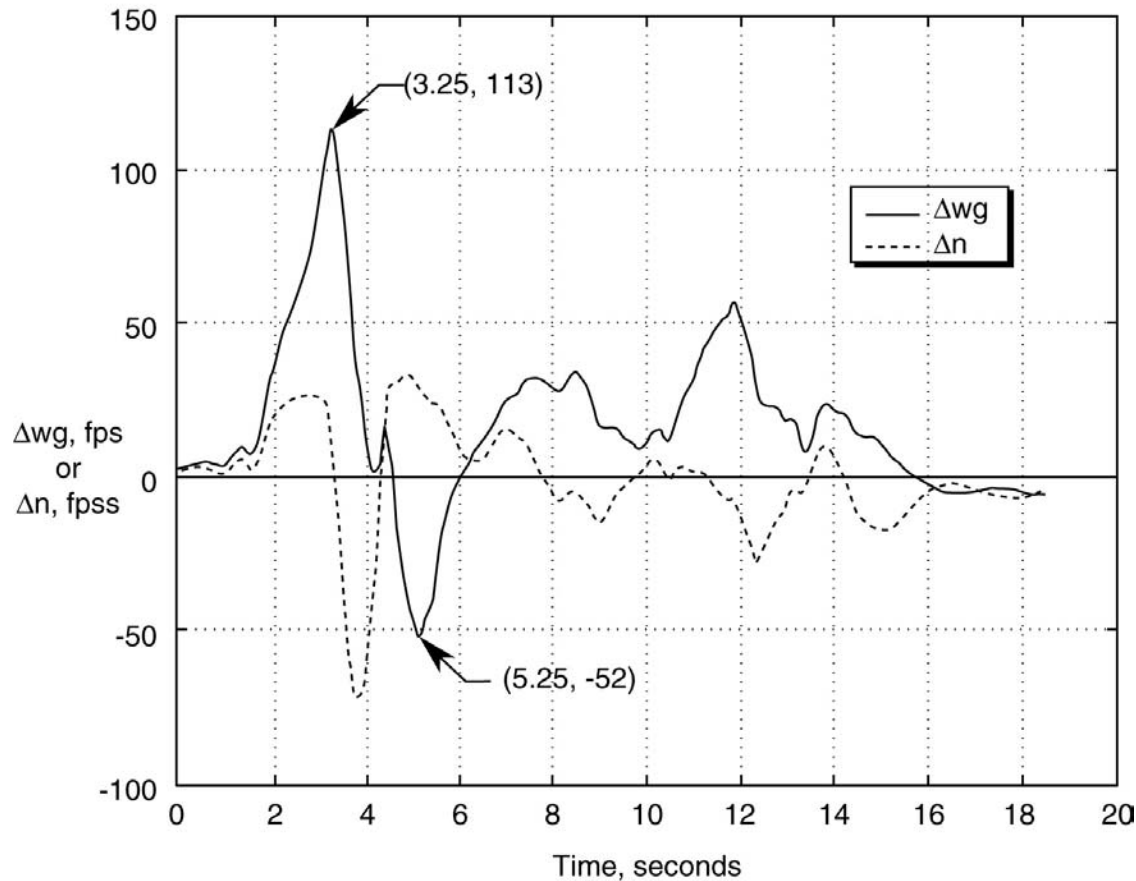
$$\Delta w_g = TAS^*(\Delta\alpha - \Delta\theta + \Delta\gamma)$$

$$\Delta\alpha = \left( \frac{W}{\bar{q}SC_{L,\alpha}} \right) \Delta n$$

$$\Delta\gamma = \frac{g}{TAS} \int \Delta n \, dt$$

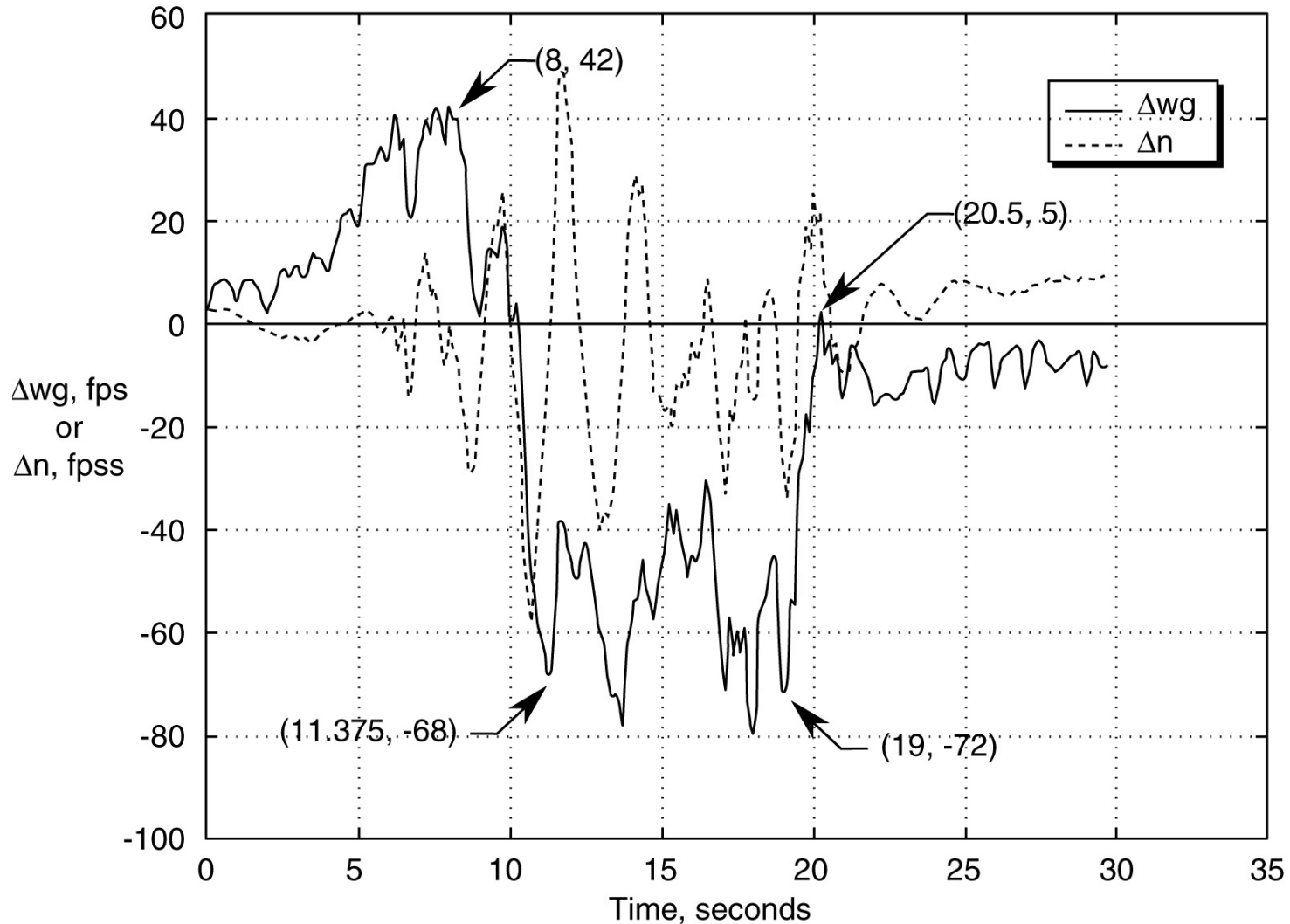
# FDR-Derived Data

737-200 A118 1997 (Accident #1)



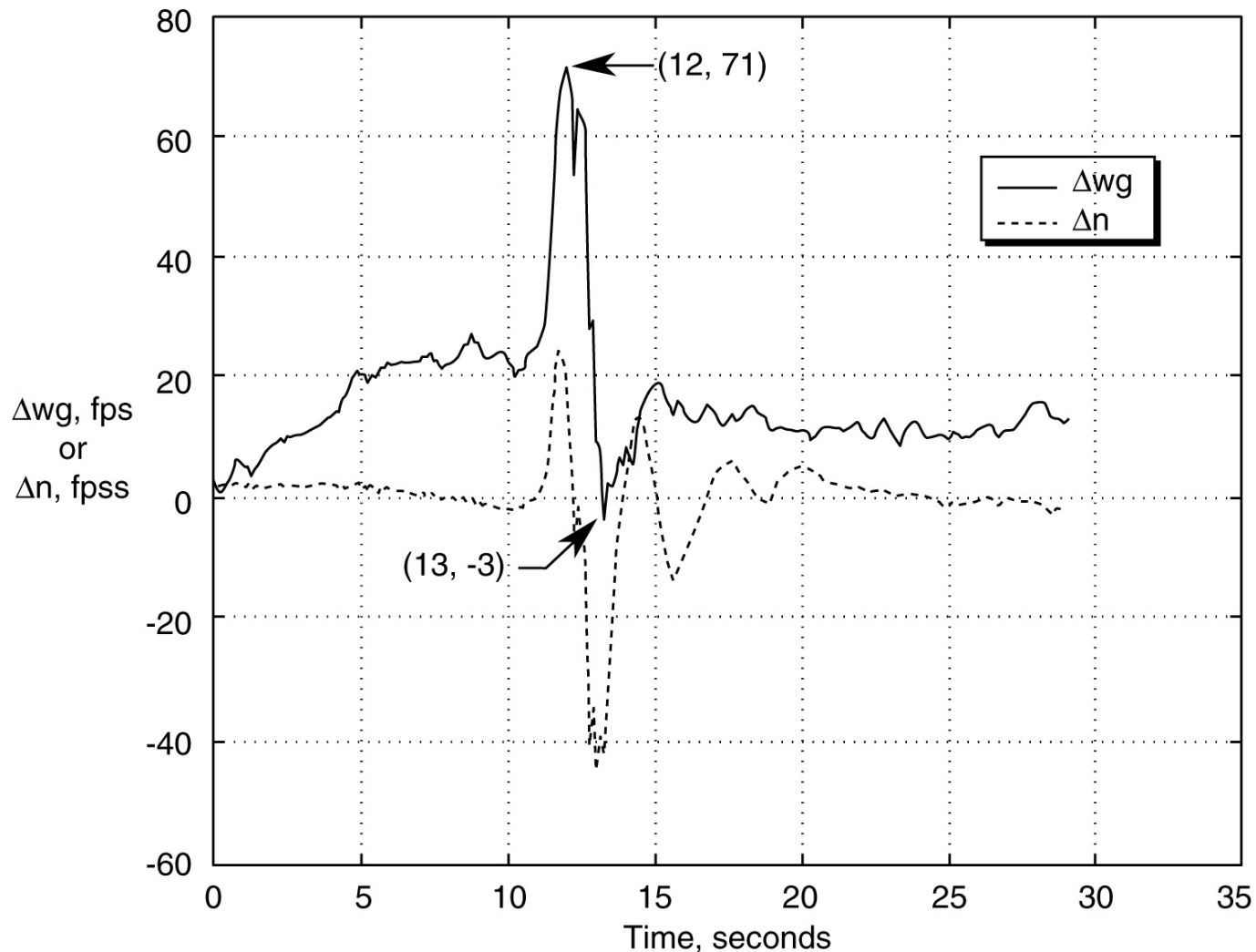
# FDR-Derived Data

## DC-9-51 Jan 1997 (Accident #2)



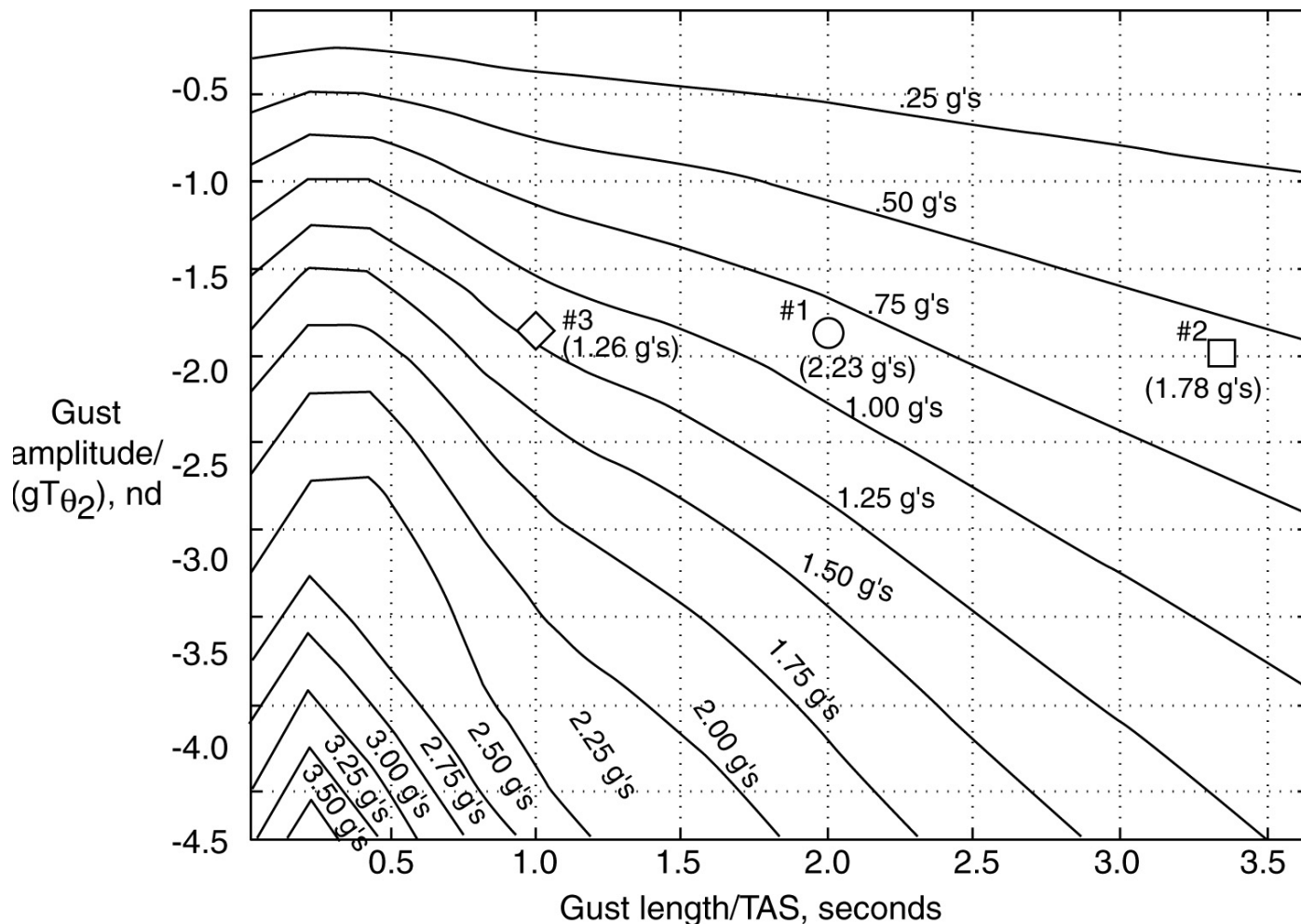
# FDR-Derived Data

## DC-9-82 Oct 1997 (Accident #3)



# Comparison of Accident Data to Math Model Predictions

(c.g. acceleration contours)



Note: Symbols are estimates for the three previous accidents

# Concluding Remarks

- A simple math model has been developed
- Model has been applied to different gust shapes and amplitudes and flight conditions
- Gust length is nearly as important as gust amplitude in predicting acceleration hazard
- Passenger collisions with cabin interior are maximum for gust lengths of 300-400 ft
- Aeroelastic effects are minimal for passenger collisions with cabin interior

# Concluding Remarks

## (concluded)

- Model predictions have been compared to NTSB recordings for three accidents
- The model-predicted accelerations are sometimes only one-half or one-third of the NTSB recordings
- The model's elevator/pitching response is less than the NTSB recordings
- The difference may be due to the autopilot disconnecting and/or pilot inputs

# Needed Future Work

- Analyze autopilot disconnect characteristics
- Determine pilot procedures/responses
- Piloted simulations in NASA's 757 simulator using NTSB gusts
- Analyze flight test data from NASA's 757
- Analyze more NTSB data